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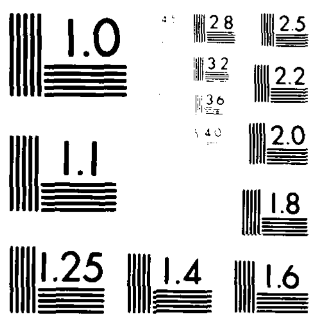


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Systems Research &
Development Service
Washington, D.C. 20590

# Operational Delay Day Forecasts for the 20 Air Route Traffic Control Centers for the Years 1982 through 2011



June 1981

Final Report

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US Department of Transportation
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NOTICE

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15. Supplementary Notes

16. Abstract


The effect of forecasts of increased traffic growth at each of the 20 CONUS Air Route Traffic Control Centers has been examined to determine the impact upon processor utilization of the Central Computer Complex at each center. The study assumes continuation of the current operational capabilities and procedures at each center, and is based upon field data collected between June 1980 and January 1981, and the June 1981 forecast of the IFR aircraft handled at the 20 Air Route Traffic Control Centers. Other factors such as channel utilization are not included in this phase of the study.


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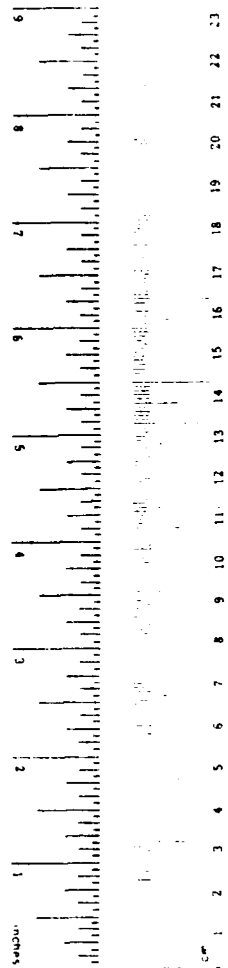
# METRIC CONVERSION FACTORS

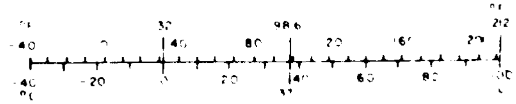
**Approximate Conversions to Metric Measures**

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



**Approximate Conversions from Metric Measures**

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## SUMMARY

The effect of forecasts of increased traffic growth at each of the twenty CONUS Air Route Traffic Control Centers has been examined to determine the impact upon processor utilization of the Central Computer Complex at each center. Other factors such as channel utilization are not included in this phase of the study, but their effects will be determined as data become available. This study assumes continuation of the current operational capabilities and procedures at each center. This study is based upon data collected between June 1980 and January 1981, under program versions 3d2.9 and 3d2.10 (without the IOCE offloading capability - see page 16).

The centers with 9020-A configurations are expected to be affected by increased traffic loads before those centers with 9020-D configurations. These increased traffic loads cause increased processor utilization which must be dealt with by using different procedures and, if conditions warrant, imposing air traffic delays in order to maintain a continued high level of safety. Of the A-sites, five may be expected to approach the processor utilization limit in the near future (within the next few years); three more A sites are forecast to approach the limits in the mid-80's, and two may not approach the limits until the late 80's.

The centers with 9020-D configurations do not become processor utilization bound until well into the 1990's or beyond. The results of the analysis are presented in summary form in Tables 1 and 2; the geographical distribution of impacted centers is presented in Figure 1.

In order to quantify the analysis, two metrics are defined. The results contained in Tables 1 and 2 and the conclusions of the report are expressed in terms of these two metrics.

An Operational Impact Day is defined to be a day during which the processor utilization exceeds 80% for a sustained period of greater than seven minutes. This is compatible with the operational procedures which call for a set pattern of cessation of selected support functions when the processor utilization exceeds 80% for a sustained period of greater than five minutes (GENOT, Reference 5). An Operational Impact Day is, then, a day when procedural cessation of selected support functions would be expected to occur at a center.

An Operational Delay Day is defined to be a day during which the processor utilization exceeds 80% for a sustained period of greater than one hour after all of the procedures of the GENOT are executed (with the exception of inclusion of the fourth processor in the 9020A's). Increase of the processor utilization beyond 80% results in slower output of necessary data to Air Traffic Controllers by the automation system. The Air Traffic Controllers restrict their requests to the automation system to essential services only and increase aircraft separation in order to continue to assure safety. In cases of a sustained period of computer overload, rerouting of en route aircraft around overloaded centers and restricting the flow of traffic into the

| FORECAST YEAR OF ONSET OF OPERATIONAL DELAY DAYS | CENTER | Z CODE | CENTRAL COMPUTER COMPLEX | FORECAST YEAR FOR ONSET OF OPERATIONAL IMPACT DAYS |
|---|---|---|---|---|
| Current | Denver | ZDV | 9020-A | Current |
| Current | Houston | ZHU | 9020-A | Current |
| Current | Miami | ZMA | 9020-A | Current |
| Current | Oakland | ZOA | 9020-A | Current |
| 1983 | Albuquerque | ZAB | 9020-A | Current |
| 1985 | Minneapolis | ZMP | 9020-A | Current |
| 1986 | Memphis | ZME | 9020-A | Current |
| 1986 | Seattle | ZSE | 9020-A | 1984 |
| 1989 | Boston | ZBW | 9020-A | 1984 |
| 1990 | Salt Lake City | ZLC | 9020-A | 1984 |
| 1997 | Los Angeles | ZLA | 9020-D | 1991 |
| 1998 | Chicago | ZAU | 9020-D | 1994 |
| 2001 | Cleveland | ZOB | 9020-D | 1995 |
| 2002 | Atlanta | ZTL | 9020-D | 1997 |
| 2002 | New York | ZNY | 9020-D | 1993 |
| 2003 | Indianapolis | ZID | 9020-D | 1997 |
| 2007 | Fort Worth | ZFW | 9020-D | 1997 |
| 2011 | Kansas City | ZKC | 9020-D | 2001 |
| Beyond 2011 | Washington | ZDC | 9020-D | 2005 |
| Beyond 2011 | Jacksonville | ZJX | 9020-D | Beyond 2011 |

TABLE 1 - FORECAST OF THE YEAR OF ONSET (  2 DAYS/YEAR) OF OPERATIONAL IMPACT DAYS AND OPERATIONAL DELAY DAYS BY CENTER

| | FORECAST YEAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CENTER | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| ZAB | 206 | 220 | 230 | 233 | 237 | 239 | 241 | 243 | 245 | 247 |
| ZAU | - | - | - | - | - | - | - | - | - | - |
| ZBW | - | 2 | 4 | 8 | 19 | 29 | 44 | 55 | 77 | 96 |
| ZDC | - | - | - | - | - | - | - | - | - | - |
| ZDV | 252 | 284 | 315 | 336 | 350 | 354 | 358 | 365 | 365 | 365 |
| ZFW | - | - | - | - | - | - | - | - | - | - |
| ZHU | 197 | 225 | 243 | 251 | 258 | 264 | 278 | 292 | 309 | 321 |
| ZID | - | - | - | - | - | - | - | - | - | - |
| ZJX | - | - | - | - | - | - | - | - | - | - |
| ZKC | - | - | - | - | - | - | - | - | - | - |
| ZLA | - | - | - | - | - | - | - | - | 2 | 6 |
| ZLC | - | 2 | 5 | 17 | 40 | 56 | 81 | 114 | 152 | 169 |
| ZMA | 149 | 201 | 267 | 315 | 343 | 351 | 359 | 365 | 365 | 365 |
| ZME | 38 | 89 | 137 | 192 | 214 | 231 | 239 | 243 | 247 | 250 |
| ZMP | 21 | 42 | 82 | 152 | 198 | 224 | 243 | 252 | 262 | 271 |
| ZNY | - | - | - | - | - | - | - | - | - | - |
| ZOA | 221 | 240 | 243 | 247 | 250 | 253 | 256 | 258 | 264 | 270 |
| ZOB | - | - | - | - | - | - | - | - | - | - |
| ZSE | - | 2 | 21 | 58 | 120 | 154 | 181 | 208 | 231 | 241 |
| ZTL | - | - | - | - | - | - | - | - | - | - |

TABLE 2A FORECAST OF OPERATIONAL IMPACT DAYS BY CENTER

| | FORECAST YEAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CENTER | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| ZAB | 2 | 5 | 24 | 48 | 104 | 141 | 178 | 205 | 223 | 230 |
| ZAU | - | - | - | - | - | - | - | - | - | - |
| ZBW | - | - | - | - | - | - | 2 | 4 | 6 | 11 |
| ZDC | - | - | - | - | - | - | - | - | - | - |
| ZDV | 31 | 77 | 152 | 218 | 264 | 291 | 313 | 331 | 342 | 351 |
| ZFW | - | - | - | - | - | - | - | - | - | - |
| ZHU | 39 | 68 | 114 | 169 | 214 | 237 | 247 | 252 | 257 | 262 |
| ZID | - | - | - | - | - | - | - | - | - | - |
| ZJX | - | - | - | - | - | - | - | - | - | - |
| ZKC | - | - | - | - | - | - | - | - | - | - |
| ZLA | - | - | - | - | - | - | - | - | - | - |
| ZLC | - | - | - | - | - | - | - | 2 | 5 | 14 |
| ZMA | 13 | 36 | 78 | 126 | 186 | 230 | 279 | 311 | 338 | 349 |
| ZME | - | - | - | 2 | 16 | 45 | 99 | 152 | 194 | 211 |
| ZMP | - | - | 2 | 8 | 26 | 51 | 90 | 147 | 192 | 218 |
| ZNY | - | - | - | - | - | - | - | - | - | - |
| ZOA | 42 | 70 | 100 | 140 | 173 | 193 | 211 | 227 | 241 | 243 |
| ZOB | - | - | - | - | - | - | - | - | - | - |
| ZSE | - | - | - | - | 7 | 30 | 64 | 105 | 142 | 164 |
| ZTL | - | - | - | - | - | - | - | - | - | - |

TABLE 2B FORECAST OF OPERATIONAL DELAY DAYS BY CENTER

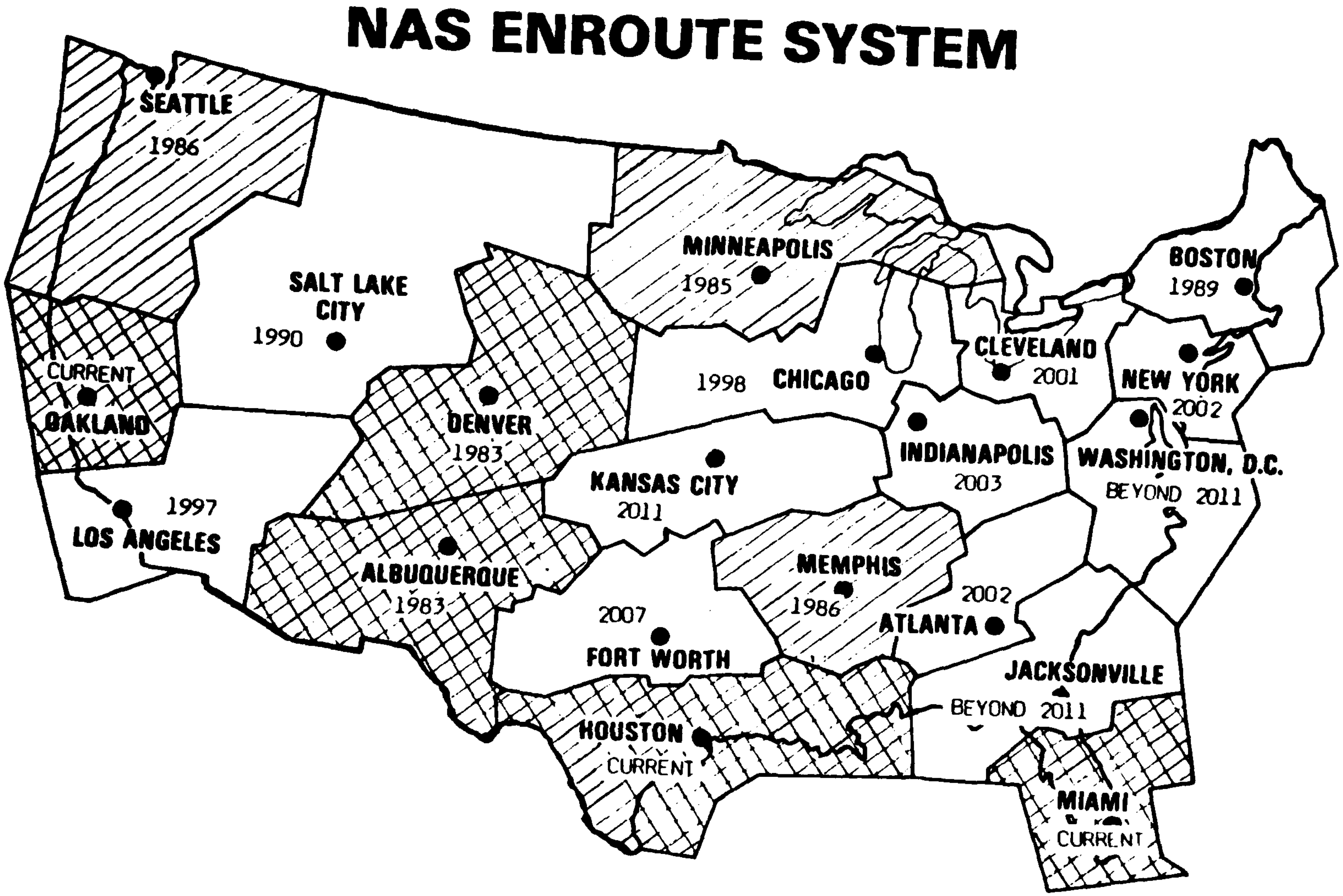


FIGURE 1 GEOGRAPHICAL DISTRIBUTION OF CENTERS SHOWING THE FORECAST FIRST YEAR WITH GREATER THAT TWO OPERATIONAL DELAY DAYS

overloaded center's airspace are used to restrict traffic to manageable load levels. An Operational Delay Day is, then, a day when the Air Traffic Control System is expected to impose air traffic delays on users due to automation system loading.

The assumptions of this analysis are consistent with those used in the traffic forecasts for each center to the year 2011. The net result of this analysis is that eight of the 9020-A sites can be expected to experience significant Operational Delay Days by the mid-80's unless some actions are taken to alleviate the situations at those centers.

Changes to the 9020 hardware and software system are currently being developed by the FAA in order to reduce processor utilization. A sensitivity analysis was thus performed assuming a 30% reduction in processor utilization, and is reported on page 16 in the section, "Further Analysis".

## INTRODUCTION

Forecasts are only as valid as the assumptions used in deriving them. The generation of the forecasts of future Central Computer Complex utilization at each center relies upon available measured relationships in order to transform forecasts of the Peak Track Count (PTC) based on peak day IFR aircraft handled (Ref. 1) into the desired Central Computer Complex utilization forecast for each center for the period 1982 through 2011. The general methodology, including the assumptions underlying the steps, will be discussed first. The definitions and interpretations of the thresholds used in this study will then be presented. The results of the computations will conclude this discussion.

## METHODOLOGY

The forecasts upon which the analysis is based are the Instantaneous Airborne Count forecasts for each center for the period 1982 through 2011, Reference 1. The transformations used to convert from the traffic forecasts to Central Computer Complex utilization forecasts include:

- the correlation relationships between Processor Utilization, Active Flight Plans, and Tracks, reported in References 2 and 3.
- the functions to be shed and the conditions under which they are to be shed, presented in Reference 5.
- the distribution of the number of days per year that the daily air traffic handled by a center will exceed a specified fraction of the yearly maximum value of daily air traffic handled by that center.
- the ratio of the maximum peak track count on a given day to the total number of IFR aircraft handled by that center on that day.
- the time distribution of aircraft traffic handled across the day for each center. An example is presented in Figure 2; data for all of the centers is contained in Reference 4.

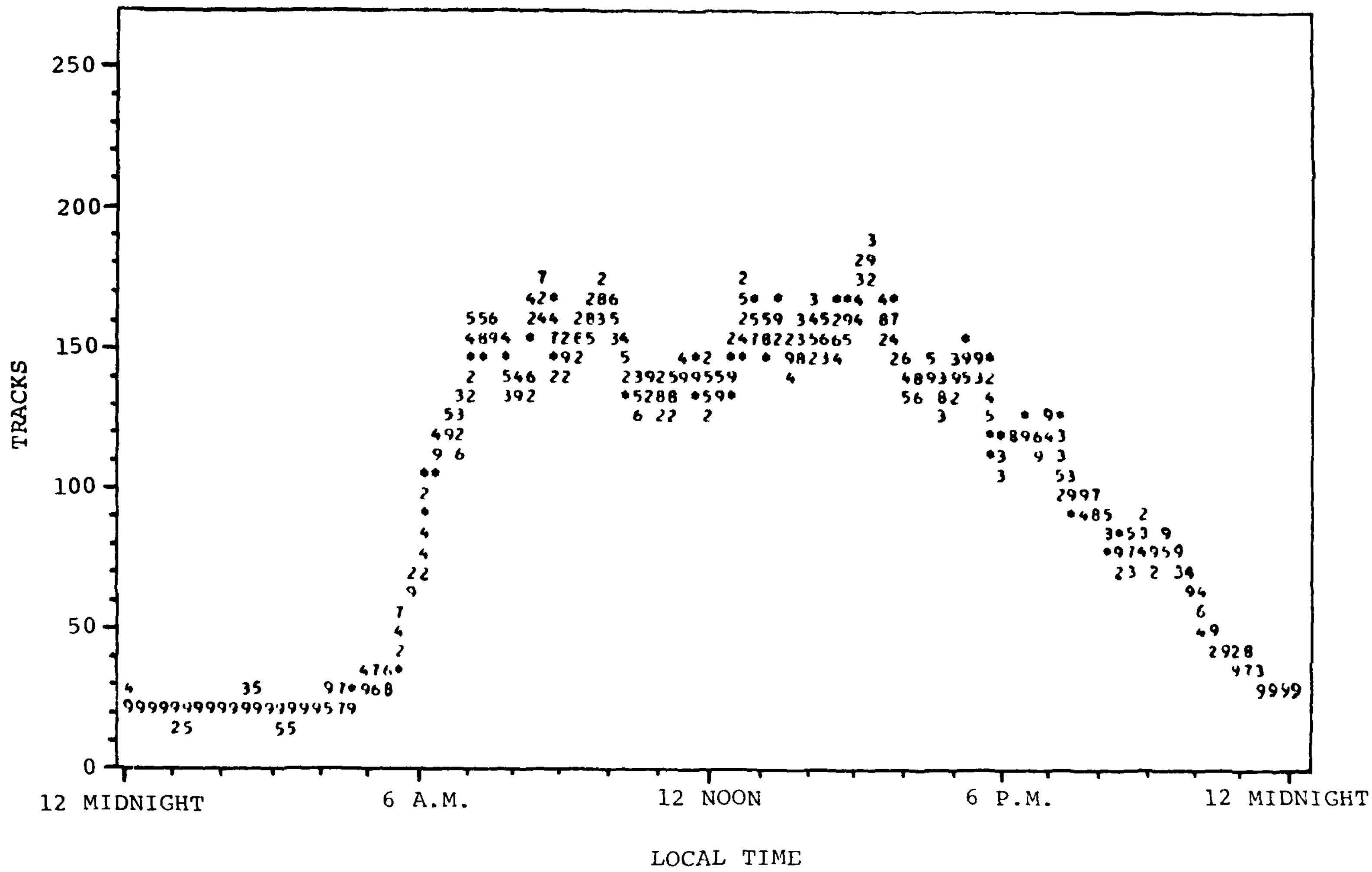


FIGURE 2 DISTRIBUTION OF AIRCRAFT TRACKS HANDLED AT HOUSTON ON JUNE 18, 1980

One of the basic assumptions made in this analysis is that the ratios and relationships among the above parameters will be relatively constant. The aircraft activity forecasts do not predict radical changes in the traffic patterns, so that it is unlikely that the above parameters will vary greatly from the values observed for them in recent years for the busiest days of the week. That is, the use of the above ratios and relationships is consistent with the assumptions used in the forecast generation (Ref. 1).

Part of the Central Computer Complex software consists of monitoring tools that can record a number of system performance observations during live ATC operations. The ON-LINE CENTRAL PROCESSING UTILIZATION MONITOR represents one of the available system monitoring tools. It was used in this study to collect for each minute the average percent of central processing consumed along with the track and flight plan load imposed on the computer.

The linear relationship found by Press (Ref 2, 3) between tracks and processor utilization provides a mapping between these two variables. The data was gathered under constant operating conditions at each center. The results show a linear correlation between the number of tracks reported in the Central Computer Complex and the processor utilization of the Central Computer Complex. It is expected that this relationship will vary as the system enters saturation at high values of processor utilization, but the empirical results indicate that the linear relationship extends up to the vicinity of 80% processor utilization, which is sufficient for the purposes of this study.

Table 3 presents pertinent parameters from that analysis. The deviations in the data collection conditions are listed, along with the values for the high end of the processor utilization range observed in that analysis. As can be seen, the measurements indicating the linear relationship between processor utilization and aircraft being tracked extend beyond values of 80% processor utilization for those centers of greatest interest to this study. The definition of the two metrics, the number of Operational Impact Days and the number of Operational Delay Days, is dependent only upon the observed properties below an 80% processor utilization for which the linear relationship has been demonstrated.

The FAA General Notice (GENOT, Reference 5) states the order of cessation of selected support functions to be accomplished when the processor utilization for the Central Computer Complex at a center exceeds 80% for a sustained 5-minute period. The steps to be taken, in the order specified in the GENOT, are:

- TURN OFF TIMING ANALYSIS REPORT SYSTEM (TARS)
- TURN OFF RESOURCE MONITORING (REMON)
- REDUCE SYSTEM ANALYSIS RECORDING (SAR) TO LOWEST LEVEL
- ADD THE FOURTH COMPUTE ELEMENT TO THE OPERATIONAL CONFIGURATION (AT THE 9020-A SITES; DSS JUDGEMENT)
- TURN OFF SYSTEM ANALYSIS RECORDING
- TURN OFF ARRIVAL DELAY RECORDING (ADR)
- TURN OFF DISPLAY INTERFACE RECORDING (DLOG)
- TURN OFF TRAINING SIMULATION (DYSIM)

| CENTER | PROGRAM VERSION | DATA GATHERING PERIOD | UPPER RANGE OF PROCESSOR UTILIZATION OBSERVED | SYSTEM STATE DEVIATIONS DURING DATA GATHERING | CORRELATION RELATION PARAMETERS SLOPE | INTERCEPT |
|---|---|---|---|---|---|---|
| ZAB | 3d2.9 | JUNE '80 | 91 | TARS PROCESSING ON, TARS RECORDING OFF | 0.338 | 10.17 |
| ZAU | 3d2.10 | JAN '81 | 45 | | 0.147 | 4.94 |
| ZBW | 3d2.9 | JULY '80 | 68 | TARS PROCESSING ON, TARS RECORDING OFF | 0.417 | 8.36 |
| ZDC | 3d2.9 | JULY '80 | 58 | | 0.148 | 5.12 |
| ZDV | 3d2.10 | AUG '80 | 85 | | 0.268 | 16.89 |
| ZFW | 3d2.10 | DEC '80 | 50 | | 0.145 | 4.61 |
| ZHU | 3d2.9 | JUNE '80 | 88 | | 0.415 | 7.50 |
| ZID | 3d2.9 | JULY '80 | 42 | | 0.161 | 3.43 |
| ZJX | 3d2.9 | JUNE '80 | 40 | TARS PROCESSING ON, TARS RECORDING OFF | 0.149 | 5.77 |
| ZKC | 3d2.9 | JULY '80 | 35 | | 0.134 | 5.23 |
| ZLA | 3d2.9 | JUNE '80 | 40 | TARS ON | 0.224 | 1.75 |
| ZLC | 3d2.9 | JUNE '80 | 68 | | 0.277 | 12.25 |
| ZMA | 3d2.9 | JUNE '80 | 75 | | 0.390 | 8.50 |
| ZME | 3d2.9 | JULY '80 | 80 | | 0.287 | 10.50 |
| ZMP | 3d2.9 | JUNE '80 | 80 | | 0.336 | 13.54 |
| ZNY | 3d2.9 | JULY '80 | 71 | TARS ON, SAR FULL | 0.247 | 6.51 |
| ZOA | 3d2.10 | OCT '80 | 87 | | 0.384 | 12.12 |
| ZOB | 3d2.9 | JUNE '80 | 55 | | 0.168 | 4.27 |
| ZSE | 3d2.10 | OCT '80 | 55 | | 0.292 | 10.02 |
| ZTL | 3d2.9 | JULY '80 | 46 | | 0.153 | 5.65 |

TABLE 3 SIGNIFICANT PARAMETERS FROM THE CORRELATION ANALYSIS (References 2, 3)

While the functions deleted have lower priority than those utilized in maintaining aircraft separation, the cessation of these functions removes valuable record keeping and analysis activities.

The effects on the processor utilization of the first three of these GENOT steps are incorporated in the data gathered for the correlation analysis, except for those cases noted in Table 3. Addition of the fourth Compute Element to the operational configuration at the 9020-A sites is specified in the GENOT to be a Data System Supervisor judgement, and is not included in this study. The inclusion of the fourth Compute Element in order to get a gain in available processor utilization risks an outage if one of the Compute Elements fails. The procedures for adding the fourth Compute Element are in preparation.

It is not required for the purposes of this study to determine the amount of processor utilization saved by each of these actions (the buy-back due to cessation of selected support functions); the total amount for all steps is sufficient. The 80% processor utilization value listed in the GENOT is used to define a set of thresholds, as will be detailed in the following sections.

Based on cursory analysis and discussions with FAA personnel, a 12% processor utilization buy-back has been used in this study, which constitutes a realistic value for the savings for the last four steps on the GENOT list. Because of the removal of all status monitoring recording during such cases, measurement of this value would prove difficult. Several independent estimates indicated that the value could be in the 12% range. As the value is optimistic, it can be safely assumed that centers still indicated to be in difficulty after the cessation of selected support functions do require further detailed consideration.

The last set of relationships required for this analysis depends upon the assumption that the slowly varying behavior of yearly changes in aircraft handled can be interpreted as an indication that distributions do not radically alter. Several of these are of interest:

a) the number of tracks in the Central Computer Complex as a function of time-of-day

b) the ratio of the peak number of tracks in the Central Computer Complex for a day to the number of IFR aircraft handled that day

c) the cumulative distribution of the IFR aircraft handled over the year normalized by the peak day IFR aircraft handled for the year.

An example illustrating the distribution of tracks at a center as a function of time-of-day is presented in Figure 2. Evaluation of the available data indicates the existence of a characteristic shape of the distribution for each center. The distribution across the day at each center reflects the distribution and scheduling of IFR aircraft flights crossing that center, and thus is expected to change slowly with time.

The latter relationship, the normalized cumulative distribution of the IFR aircraft handled, is found by forming the ratio of the daily IFR aircraft handled to the peak day IFR aircraft handled, and ordering the ratios by decreasing value of the ratio. This yields a function which specifies, for a given value of the ratio, the number of days for which the IFR aircraft handled was equal to or greater than that fraction of the peak day IFR aircraft handled. Let x denote the ratio:

$$x = \frac{\text{daily IFR aircraft handled}}{\text{peak day IFR aircraft handled}} .$$

If the ratio of the peak number of tracks in the Central Computer Complex for a day to the number of IFR aircraft handled for that day is roughly a constant, then the normalized cumulative distribution may be expressed in terms of the ratio of the Peak Track Count (PTC) for the day of interest to the Peak Track Count for the peak day of the year, so that now

$$x = \frac{\text{PTC for the day of interest}}{\text{PTC for the peak day of the year}} .$$

A sample normalized cumulative distribution is presented in Figure 4. The consistency of the shapes of the distributions between centers is illustrated in Figure 3. The distributions are composed of two plateaus, one extending from about 20 days to about 250 days, and a second from about 250 days to 360 days. The first plateau generally represents the traffic handled on week days; the second plateau generally represents the traffic handled on weekends. The distribution of travel patterns within a week are not expected to vary greatly.

The number of days for which a center's processor utilization requirements may be expected to exceed some threshold can be found by converting the threshold to track equivalent using the observed correlation relations and determining the position on the distribution curve.

$$\text{track equivalent} = \frac{\text{threshold - intercept}}{\text{slope}} .$$

Let m and b denote the empirically determined slope and intercept from the correlation relations determined for each center, and C the desired processor utilization threshold value. The expression becomes

$$\text{track equivalent} = T = \frac{C - b}{m} .$$

Let the normalized cumulative distribution be denoted by g(x). The value of the distribution is then given by

$$g = \frac{\text{track equivalent}}{\text{peak day PTC}} = \frac{T}{\text{PTC}} = \frac{C - b}{m * (\text{PTC})} .$$

where PTC is now taken to refer to the peak day PTC for the year under consideration. With the value of the distribution g determined, the corresponding number of days which are expected to exceed this value can be picked from the observed normalized cumulative distribution for the

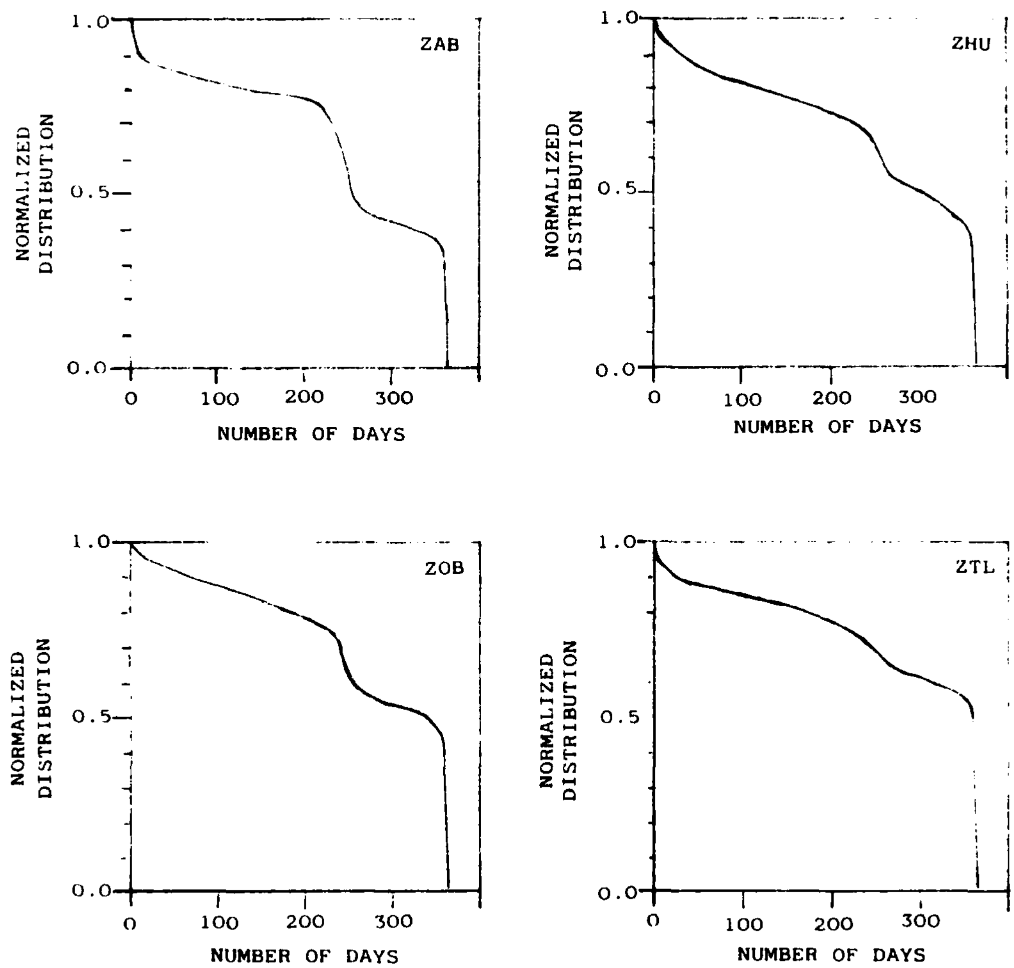


FIGURE 3 NORMALIZED DISTRIBUTIONS OF THE NUMBER OF AIRCRAFT HANDLED OVER A PERIOD OF ONE YEAR AT SEVERAL REPRESENTATIVE ARTCC'S

$$\frac{T_{80}}{PTC} = \frac{175}{238} = 0.735, \quad D{>}80\% = 196$$

$$\frac{T_{80'}}{PTC} = \frac{211}{238} = 0.887, \quad D{>}80'\% = 39$$

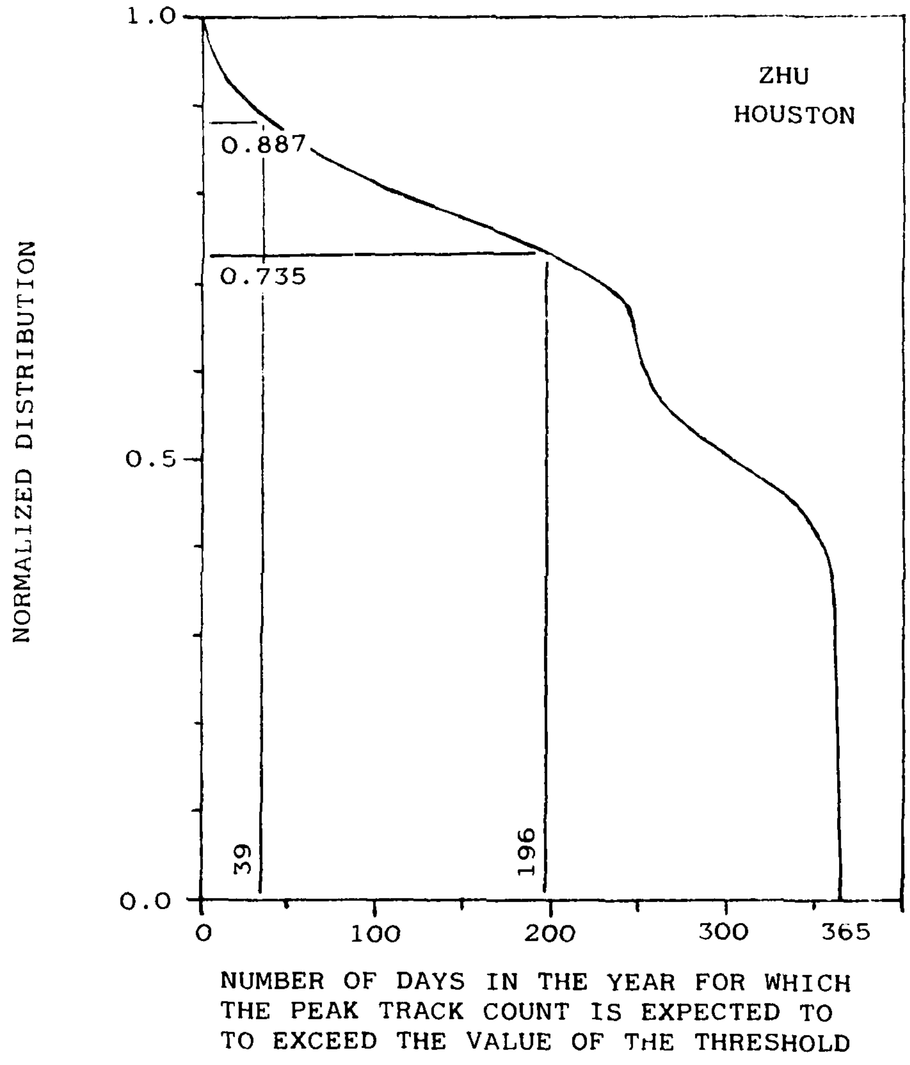


FIGURE 4 DETERMINATION OF THE NUMBER OF OPERATIONAL DELAY DAYS AND THE NUMBER OF OPERATIONAL IMPACT DAYS

center, as illustrated in Figure 4. Here $T_{80}$ is the track equivalent corresponding to a processor utilization threshold C of 80%, the value of the utilization used in the definition of Operational Impact Day.

When buy-back is included, the processor utilization threshold must include the appropriate terms for the buy-back. Let the total threshold be given by:

$$C = TH + BB + DL$$

where TH = threshold level in percent

BB = buy-back processor utilization value in percent

DL = delay affect.

For this study, the threshold level TH is 80% (corresponding to the value in the GENOT), the buy-back processor utilization BB is 12% (corresponding to the processor utilization gain assumed for the completion of cessation of selected support functions), and the delay effect DL (the amount of processor utilization advantage gained by accepting operational impact for a specified time duration) must be determined for each center. Values for DL for the centers range between 0% and 4% assuming that the first hour of computer overhead can be absorbed by the center operations.

The general case is then

$$g(x) = \frac{TH + BB + DL - b}{m * (PTC)} ,$$

where x represents the number of days for the year for which the maximum processor utilization usage is expected to exceed the threshold C.

$T_{80}'$ in Figure 4 corresponds to this relationship with

TH = 80%

BB = 12%

DL = value determined for each center

m, b = values determined for each center in the correlation analysis.

Saturation onset occurs when $g(x) = 1$. Solving for the corresponding value of PTC for $g(x) = 1$:

$$PTC = \frac{TH + BB + DL - b}{m} .$$

The year for which the forecast PTC has this value corresponds to the year when the specified threshold is first exceeded.

Thereafter, g can be estimated from

$$g(x) = \frac{TH + BB + DL - b}{m * (PTC)},$$

and the number of days x for which the threshold is exceeded can be estimated from the observed normalized cumulative distributions, as in Figure 4.

A calculation of one of the data points may be the best way to provide an understanding of the analysis methodology. Houston center in 1982 is selected as the example. The forecast peak track count for Houston in 1982 is 238 tracks (reference 1). From Table 3 the mapping between processor utilization and tracks is:

$$\text{processor utilization} = 7.50 + 0.415 * \text{TRACKS}.$$

Using this relationship, the 80% processor utilization threshold specified in the GENOT is found to be 175 tracks. Thus, cessation of selected support functions is expected to be called for when the automation system track load exceeds 175 active aircraft tracks for Houston center. This constant is denoted by $T_{80}$.

A second constant, $T_{80}'$, is also defined. This constant corresponds to the number of tracks in the system when the processor utilization reaches 80% for a sustained period of one hour after the cessation of selected support functions specified in the GENOT is accomplished.

The buy-back in processor utilization as a result of the specified cessation of selected support functions is estimated to be 12%. Examination of the distribution of active tracks across a busy day for Houston indicates that a one-hour absorption of computer saturation is equivalent to a buy-back of about 3%. The equivalent threshold is then 80% + 12% + 3% = 95%. The corresponding number of tracks, found by solving the correlation relationship, is 211 active tracks.

The two threshold values, divided by the forecast maximum Peak Track Count for the year, gives the normalized distribution values corresponding to the two thresholds.

$$\frac{T_{80}}{PTC} = \frac{175}{238} = 0.735, \qquad \frac{T_{80}'}{PTC} = \frac{211}{238} = 0.887.$$

These values are entered in the normalized cumulative distribution for Houston, given in Figure 4, and the corresponding number of days exceeding the criteria are determined from the curve.

## RESULTS

The results of this analysis are summarized in Figures 5 and 6. Plotted here are the number of Operational Delay Days for each center for each year in the projection period. The centers with 9020-D complexes do not have potential processor utilization problems until late in the forecast period. Eight of the 9020-A complexes indicate the onset of processor utilization problems in the early to mid-1980's.

The curve for each center has two characteristics of interest, the year of the delay onset and the rate of increase thereafter. The year of delay onset depends upon the values of all of the constants used in the analysis. The rate of increase after onset, however, is dependent mainly upon the forecast yearly traffic increase and the shape of the normalized distribution function for each center. The shape of the normalized distribution is not likely to change markedly; thus, once the threshold is passed and Operational Delay Days start for a center, it may be expected that the number of Operational Delay Days will increase rapidly over a short interval of years.

The year of onset depends upon the assumed stability of several relationships and the number of aircraft in the traffic forecasts. The near-term forecast values may be expected to be accurate, thus centers which are expected to enter problem times in the near term have a good probability of being properly identified.

## FURTHER ANALYSIS

It should be emphasized that this analysis is based on the data collected and analyzed in References 2, 3, and 4. The FAA is making changes to the 9020 hardware and software system to reduce processor utilization. The most notable of these is an extra storage element added to the Central Computer Complex and the offloading of some processing to the Input-Output Compute Element in software version 3d2.10. Data is being collected to measure these gains and will be analyzed upon receipt.

However, in order to quantify possible gains in processor utilization as well as to provide a sensitivity analysis to the foregoing results, an additional analysis has been performed. This analysis was performed using an assumed value of 30% for the buy-back processor utilization (BB) in the expression for the normalized cumulative distribution g(x) (page 14), computing the new values of the distribution, and then determining the number of days for which the threshold is exceeded from the empirical curves.

The results of the analysis are shown in Table 4. The basic results remain unchanged but shifted in time. Four center's exhibit operational delays in the mid-1980's. A comparison with Table 2 shows that the onset of the impacts have been delayed, but that processor capacity problems will continue to plague the FAA at certain centers throughout the 1980's.

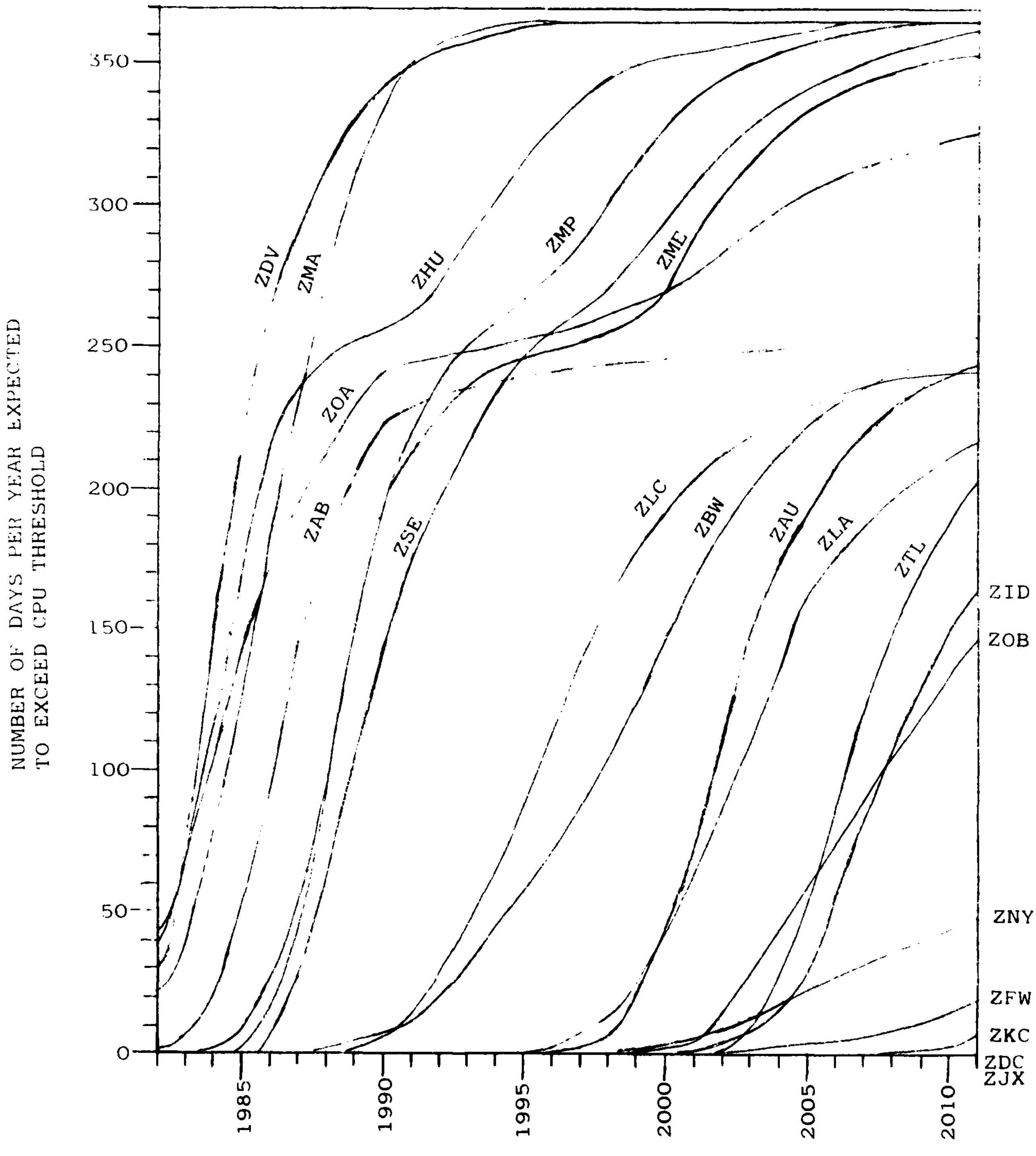


FIGURE 5 FORECAST NUMBER OF OPERATIONAL DELAY DAYS BY CENTER

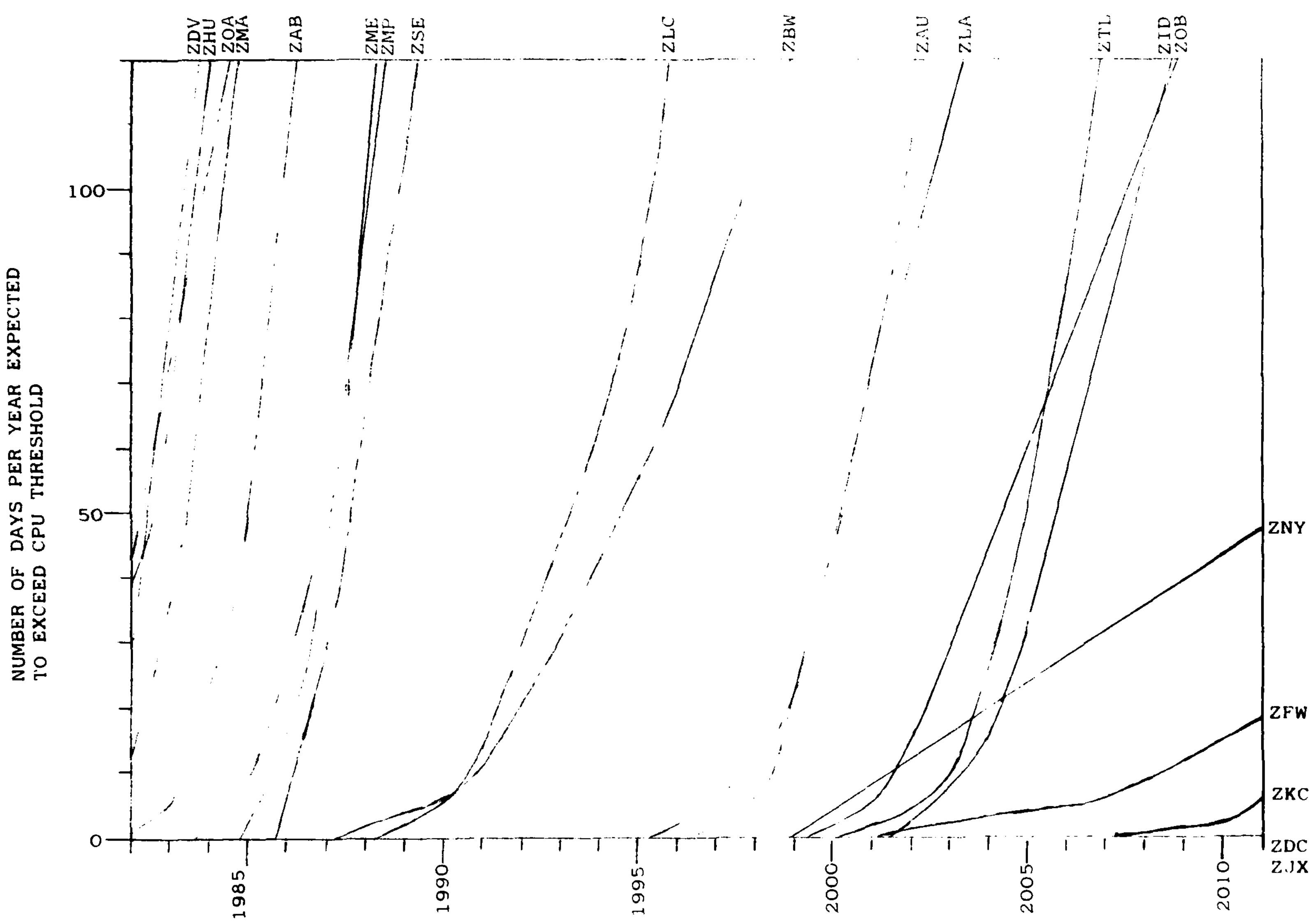


FIGURE 6 FORECAST NUMBER OF OPERATIONAL DELAY DAYS BY CENTER - DETAIL TO SHOW RATE OF GROWTH AT ONSET

| | FORECAST YEAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CENTER | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| ZAB | – | – | – | – | – | – | – | – | 2 | 2 |
| ZAU | – | – | – | – | – | – | – | – | – | – |
| ZBW | – | – | – | – | – | – | – | – | – | – |
| ZDC | – | – | – | – | – | – | – | – | – | – |
| ZDV | – | – | – | – | 2 | 5 | 19 | 39 | 85 | 139 |
| ZFW | – | – | – | – | – | – | – | – | – | – |
| ZHU | – | – | – | – | 8 | 21 | 47 | 75 | 124 | 160 |
| ZID | – | – | – | – | – | – | – | – | – | – |
| ZJX | – | – | – | – | – | – | – | – | – | – |
| ZKC | – | – | – | – | – | – | – | – | – | – |
| ZLA | – | – | – | – | – | – | – | – | – | – |
| ZLC | – | – | – | – | – | – | – | – | – | – |
| ZMA | – | – | – | – | – | 4 | 11 | 24 | 60 | 90 |
| ZME | – | – | – | – | – | – | – | – | – | – |
| ZMP | – | – | – | – | – | – | – | – | 2 | 2 |
| ZNY | – | – | – | – | – | – | – | – | – | – |
| ZOA | – | – | – | – | – | – | 2 | 2 | 21 | 29 |
| ZOB | – | – | – | – | – | – | – | – | – | – |
| ZSE | – | – | – | – | – | – | – | – | – | – |
| ZTL | – | – | – | – | – | – | – | – | – | – |

TABLE 4 SENSITIVITY ANALYSIS RESULTS FOR FORECAST OF OPERATIONAL DELAY DAYS BY CENTER

## REFERENCES


Reference 1 Instantaneous Airborne Counts, A Preliminary Report of Studies Underway at the Office of Aviation Policy and Plans, Information Systems Branch, May 1981

FAA Forecast of Air Route Traffic Control Center IFR Aircraft Handled and Instantaneous Airborne Counts; FY 1981 - 2011, Office of Aviation Policy and Plans, June 1981

Reference 2 Computer Utilization at Several En Route Air Traffic Control Centers (A3d2.9 System), Jacques Press, ARD-140-1-81, December 1980

Reference 3 Computer Utilization at Several En Route Air Traffic Control Centers (A3d2.10 System), Jacques Press, ARD-140-8-81, June 1981

Reference 4 Traffic Loads and Computer Utilization Patterns at the Twenty En Route Air Traffic Control Centers, Jacques Press, ARD-140-8-81, June 1981

Reference 5 GENOT RWA 8/11, dated January 20, 1978

Paragraph 1024, System Saturation Warning Procedures, FACILITY OPERATION AND ADMINISTRATION, FAA Directive 7210.3E, August, 1979

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